Optical Model Potential in Rare-earth Region

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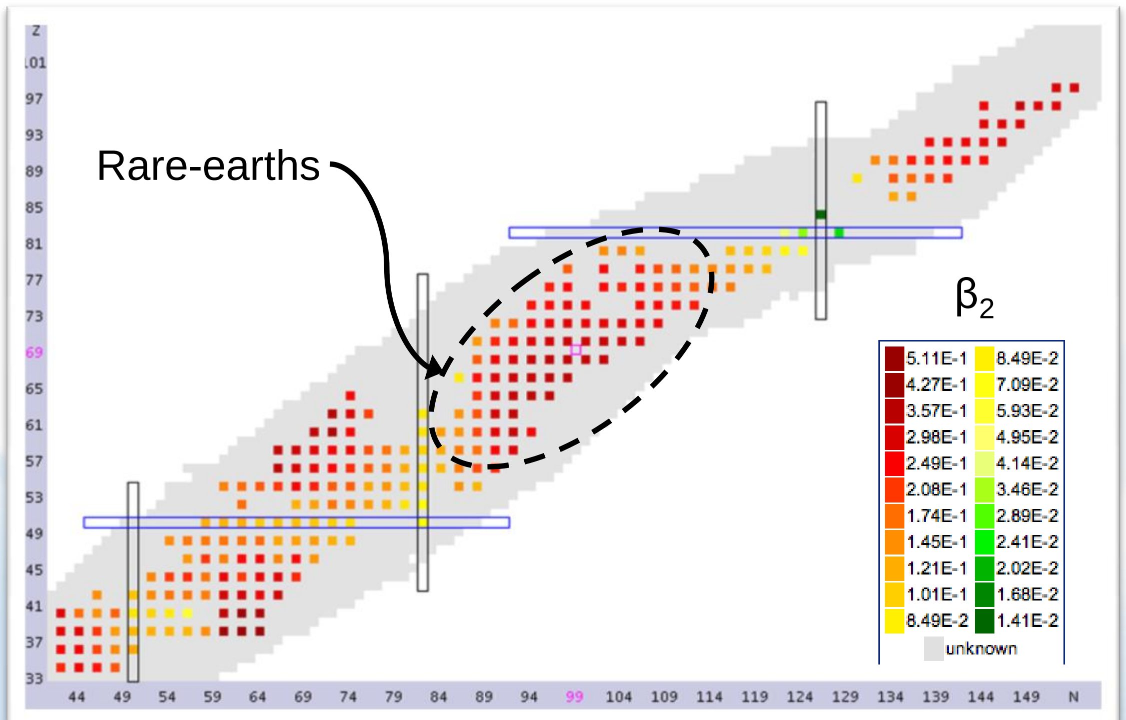
Motivation

- Why seek an optical potential for this region?
  - Lack of existing regional OP's for deformed nuclei
  - Recent work* shows scattering from highly deformed nuclei is near adiabatic limit ➔ deforming a spherical global potential may be suitable with only minor modifications

We deform the Koning-Delaroche spherical global potential and couple g.s. rotational band



- Another approach (Kunieda *et al.* §) fitted a global OP considering all studied nuclei as rigid rotors

* Phys. Rev. C 85 (2012) 044611
§ J. Nucl. Sci. Tech. 44 (2007) 838

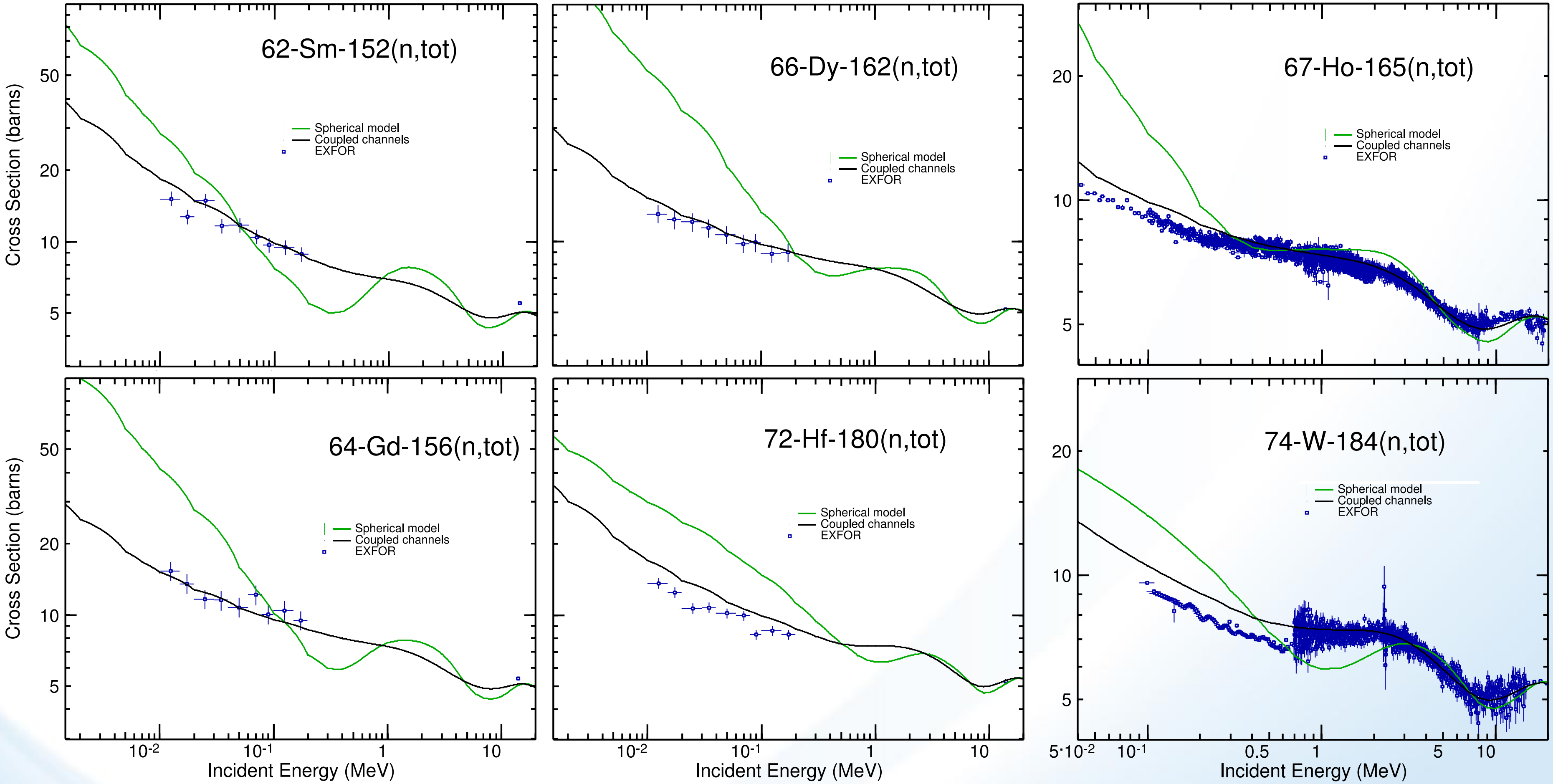
Initial calculations done in rare-earths region

- CC calculations deforming spherical Koning-Delaroche OP
  - Full imaginary part of KD
  - Adiabatic limit
  - Experimental deformations
  - Coupled to g.s. rotational band

$$R(\theta) = R_0\left(1+\sum_{\lambda} \beta_\lambda Y_{\lambda,0}(\theta)\right)$$

- Used EMPIRE code (Direct reaction part calculated by ECIS)
- 34 nuclei: ^{162,163,164}Dy, ^{166,167,168,170}Er, ^{153}Eu, ^{155,156,157,158,160}Gd, ^{177,178,179,180}Hf, ^{165}Ho, ^{175,176}Lu, ^{152,154}Sm, ^{181}Ta, ^{159}Tb, ^{169}Tm, ^{182,183,184,186}W, ^{171,172,173,174,176}Yb
- Tested convergence to the number of channels and correction for volume conservation
- Initially compared direct-reaction observables; then extended approach to test effect on compound nucleus quantities

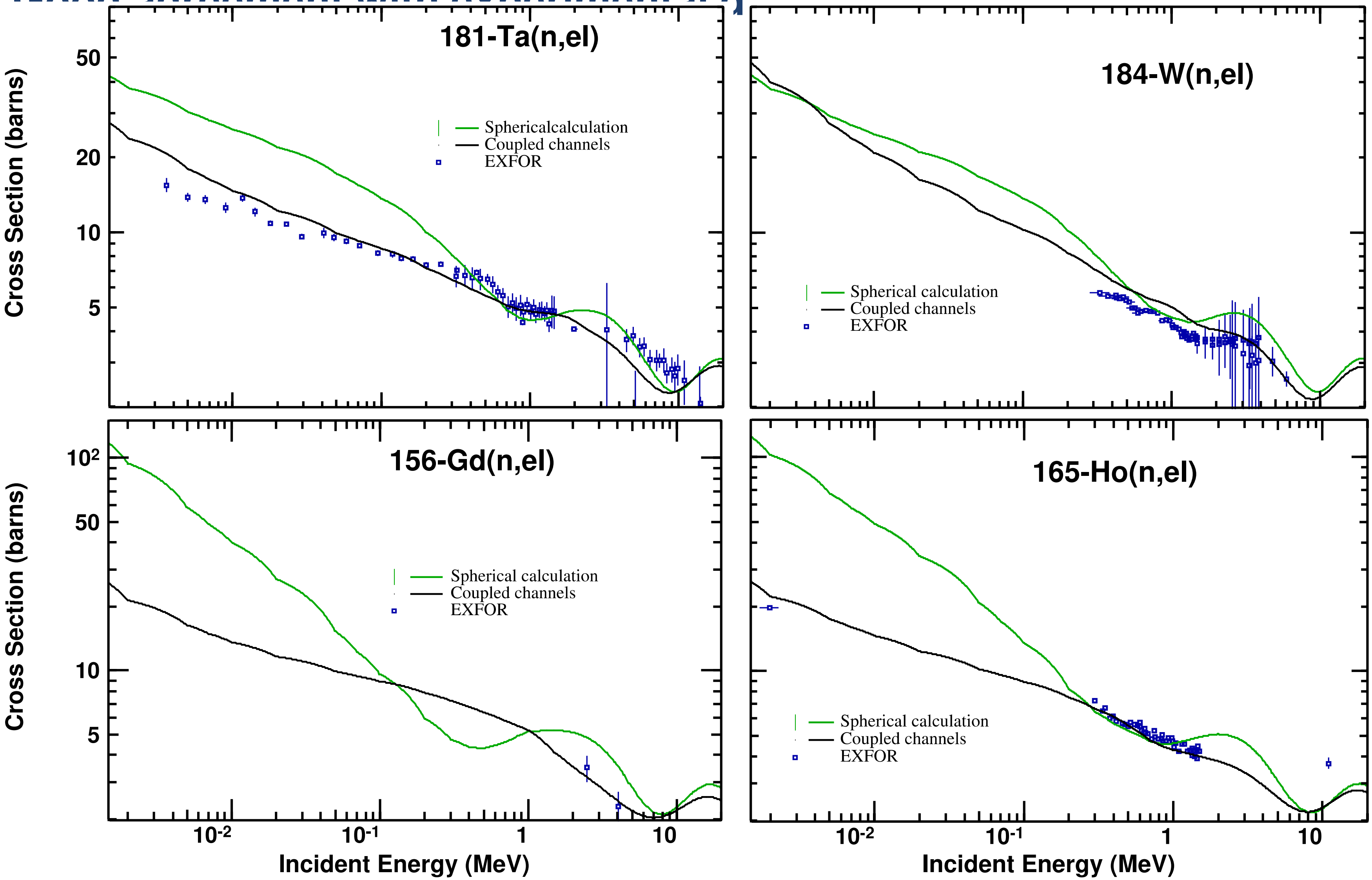
Comparison between spherical and CC:
Total cross sections



Spherical approach fails at low energy and its shape is often in disagreement with experimental data, while deforming KD potential provides a good description of the observed total cross sections

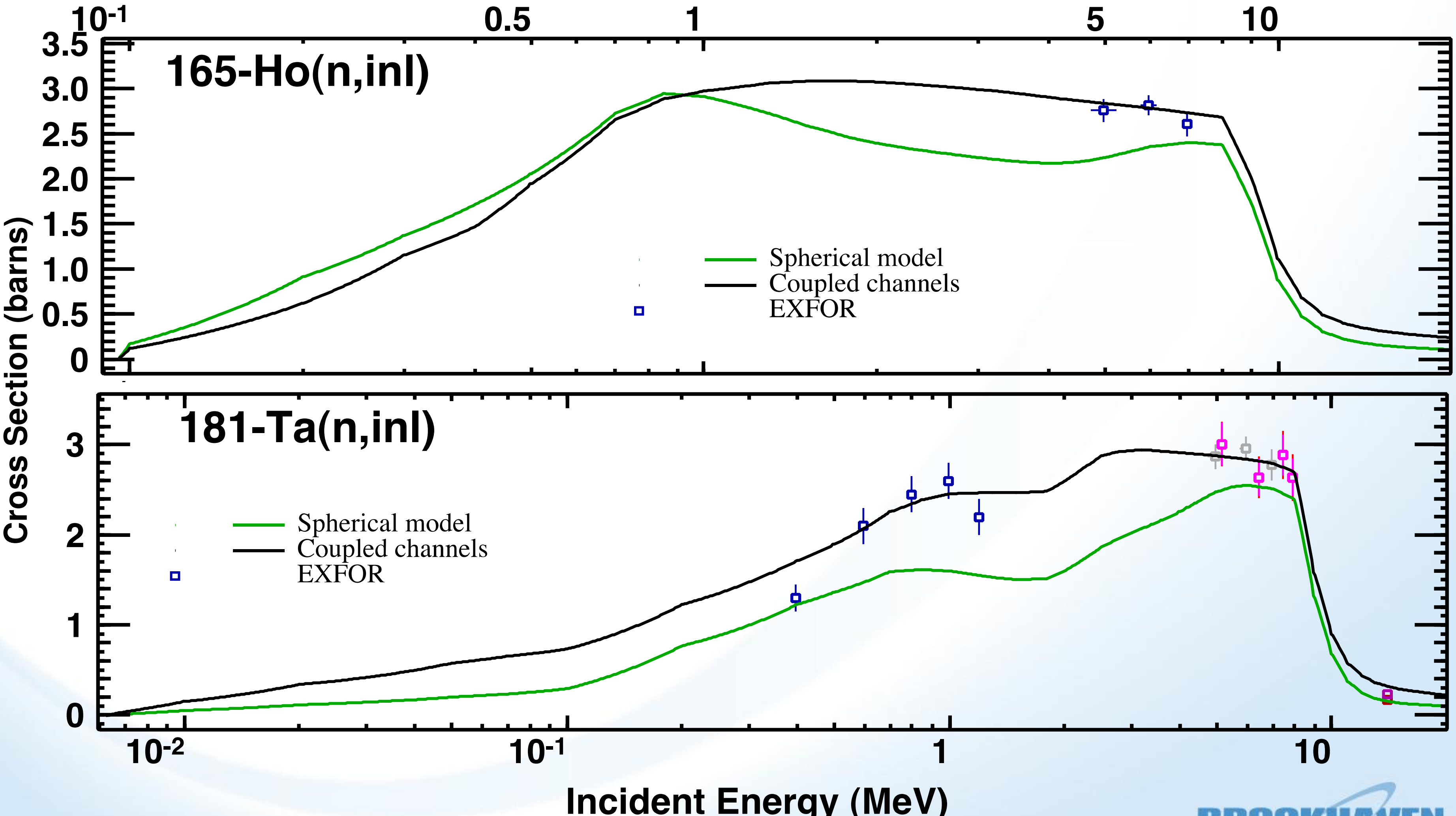
Elastic cross section (shape + compound)

Good agreement with experimental d



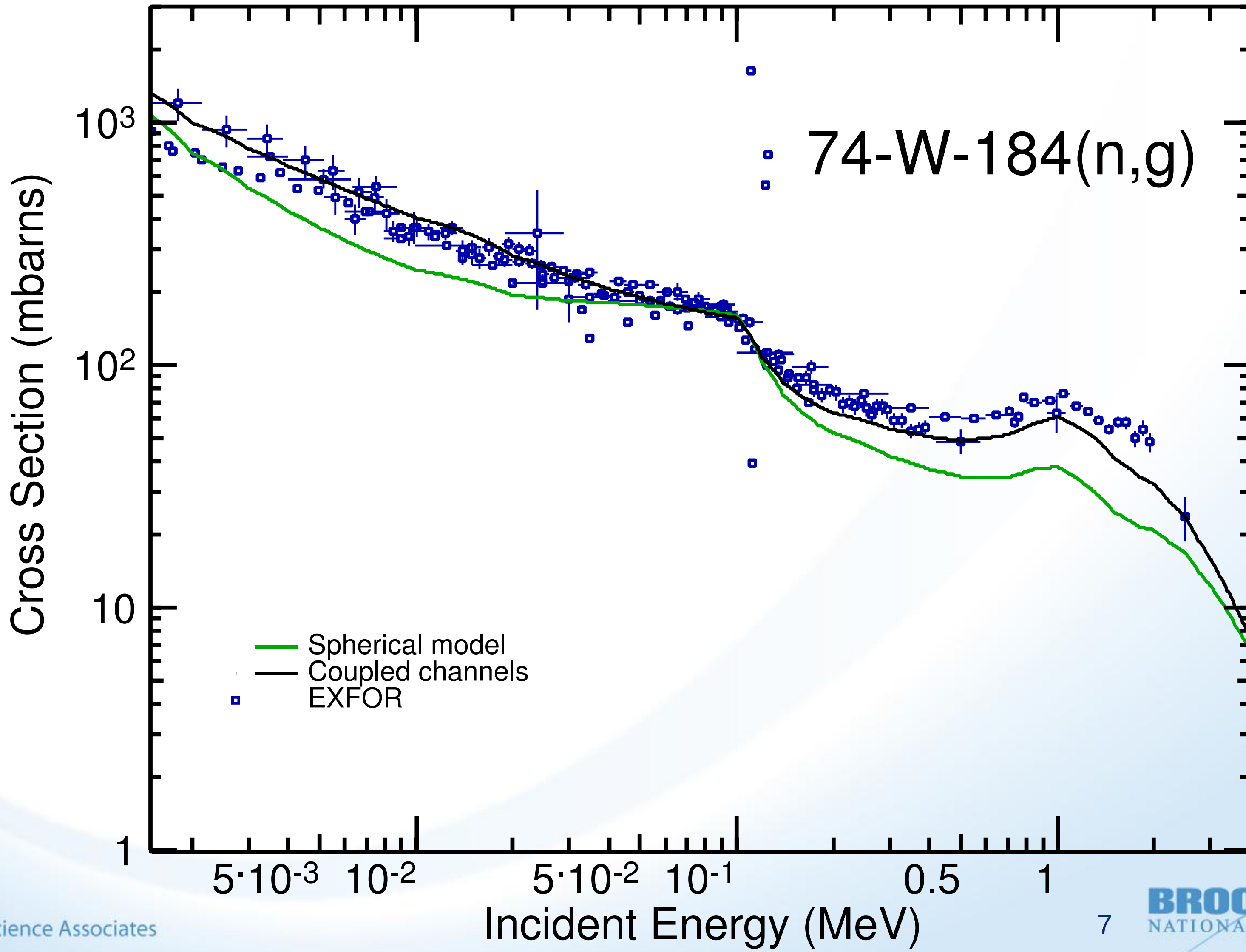
Total inelastic

Clear improvement on the agreement to total inelastic experimental data



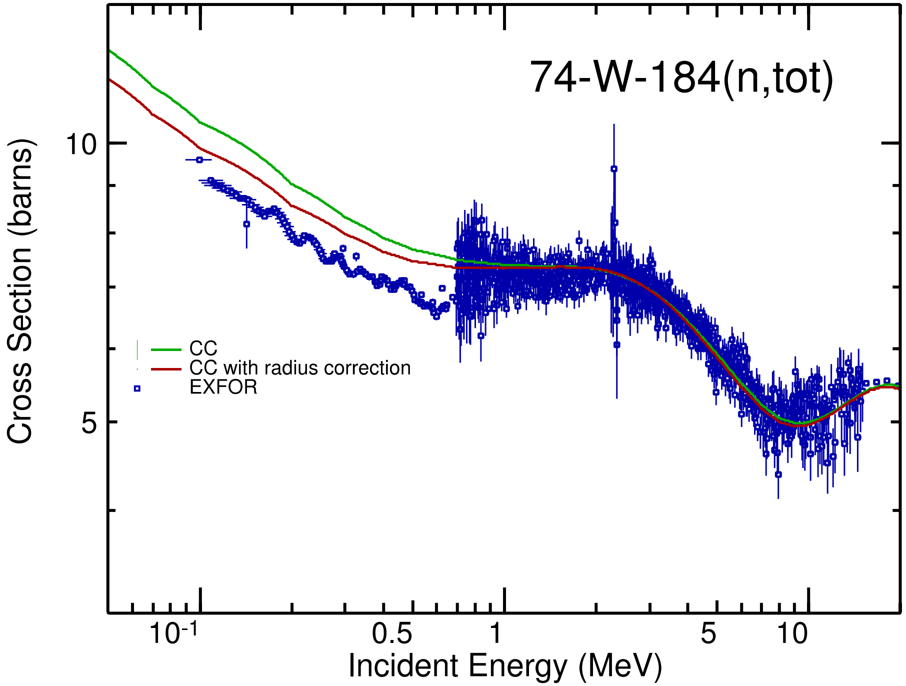
Capture cross sections

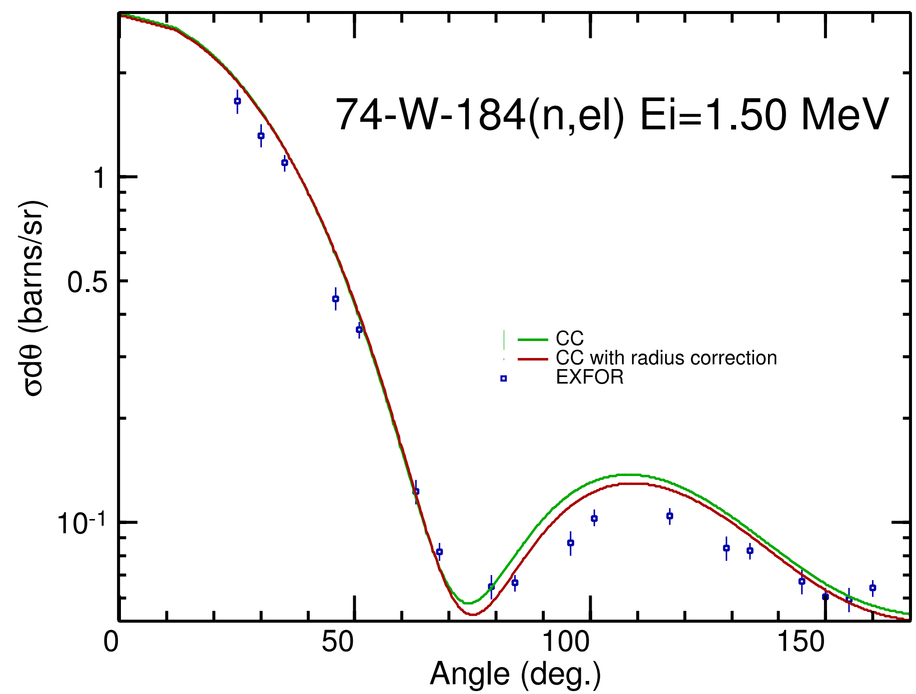
Our model gives a very good description of capture cross sections



When deforming the potential, the volume should be conserved

- Bang & Vaagen§: $R_0^{'} = R_0\left(1 - \sum \beta_l^2 / 4\pi\right)$
- For ^{184}W: $\beta_2=0.236$ □ $\Delta < 0.5\%$
- Most deformed: ^{160}Gd: $\beta_2=0.353$ □ $\Delta < 1\%$



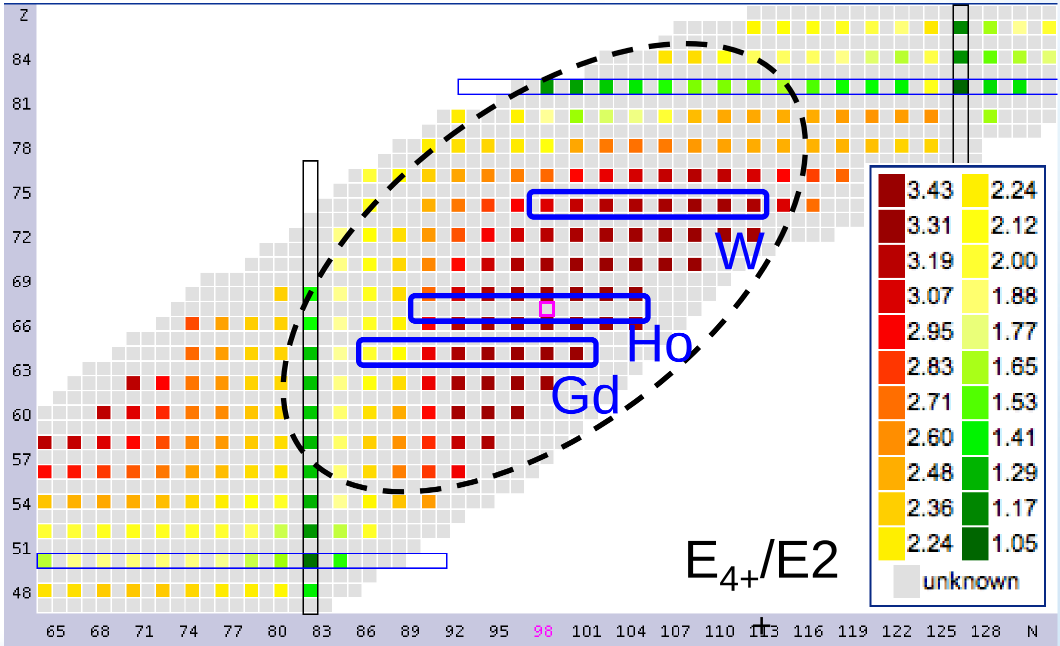


§Z. Physik A 297 (1980) 223

Angular distributions: Gd, Ho, W

- More detailed analysis on the experimental data sets
- Some elastic ang. dist. data actually contained inelastics
- Ensured convergence regarding number of rotational channels

nucleus	β_2*	β_4§	Δ_R	$\beta_2^{(sys)}$¶
^{158}Gd	0.348	0.056	0.990	0.362
^{160}Gd	0.353	0.056	0.990	0.372
^{165}Ho	0.293	-0.020	0.993	0.385
^{182}W	0.251	-0.080	0.995	0.268
^{184}W	0.236	-0.080	0.996	0.255
^{186}W	0.226	-0.080	0.996	0.226

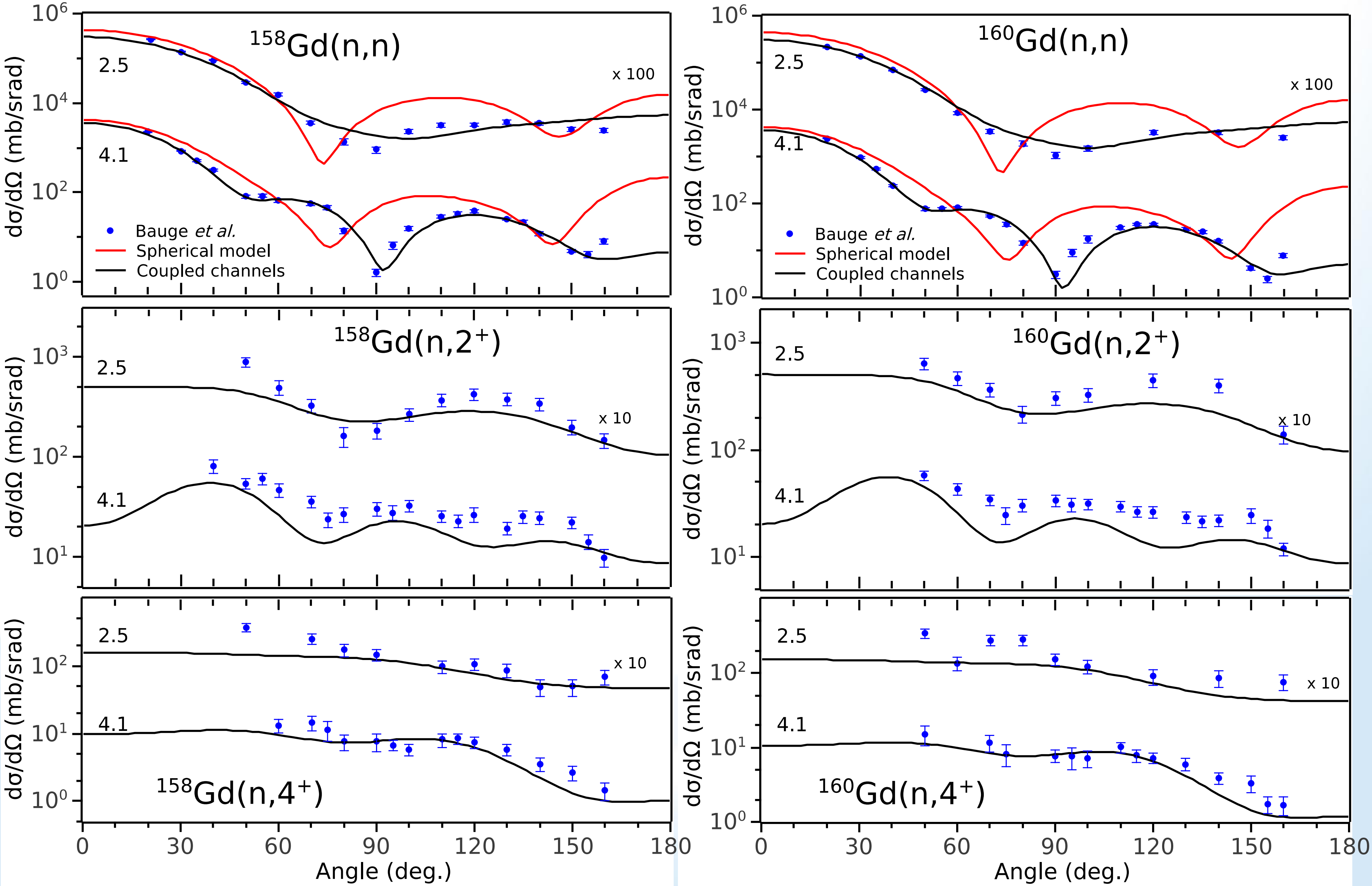


* At. Data. Nucl. & Data Tables, 78, (2001) 1
§ Ann. Nucl. Energy, 31 (2004) 1813; Phys. Lett. 26B (1968) 127; Ann. Nucl. Energy, 28 (2001) 1745

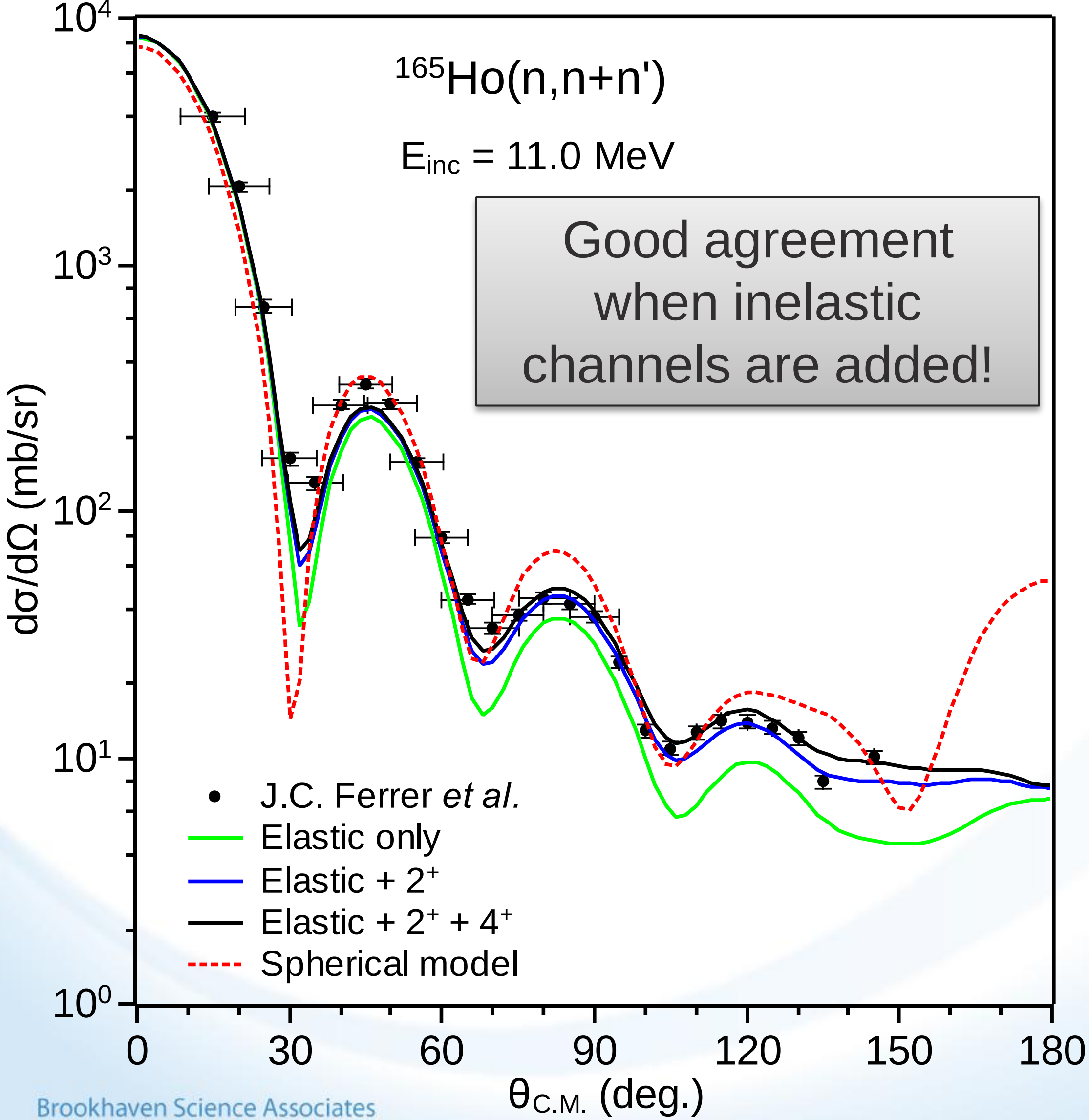
¶ Phys. Rev. C 70 (2004) 014604; Phys. Rev. C 76 (2007) 024605

^{158,160}Gd Angular distributions

Good agreement with experimental data obtained by the model

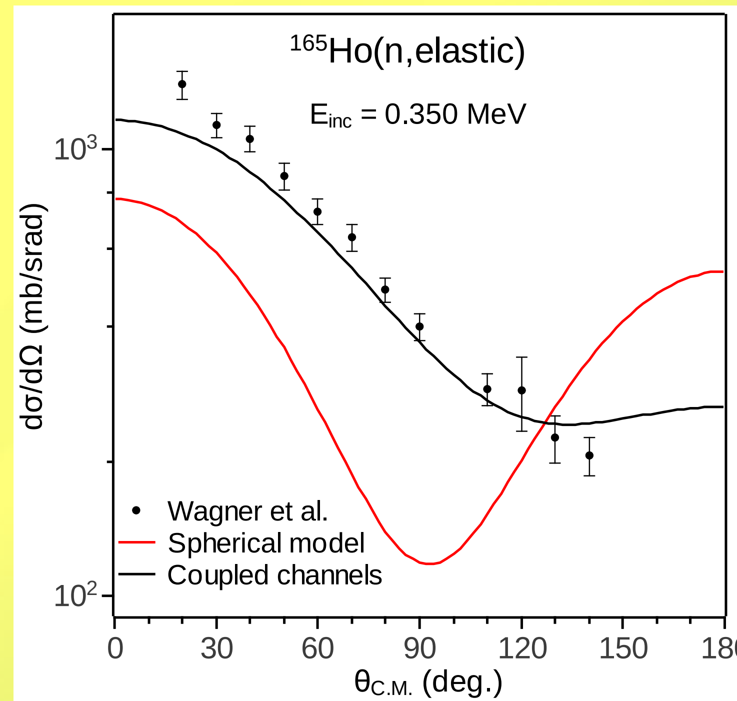


^{165}Ho “Quasi-elastic” angular distributions



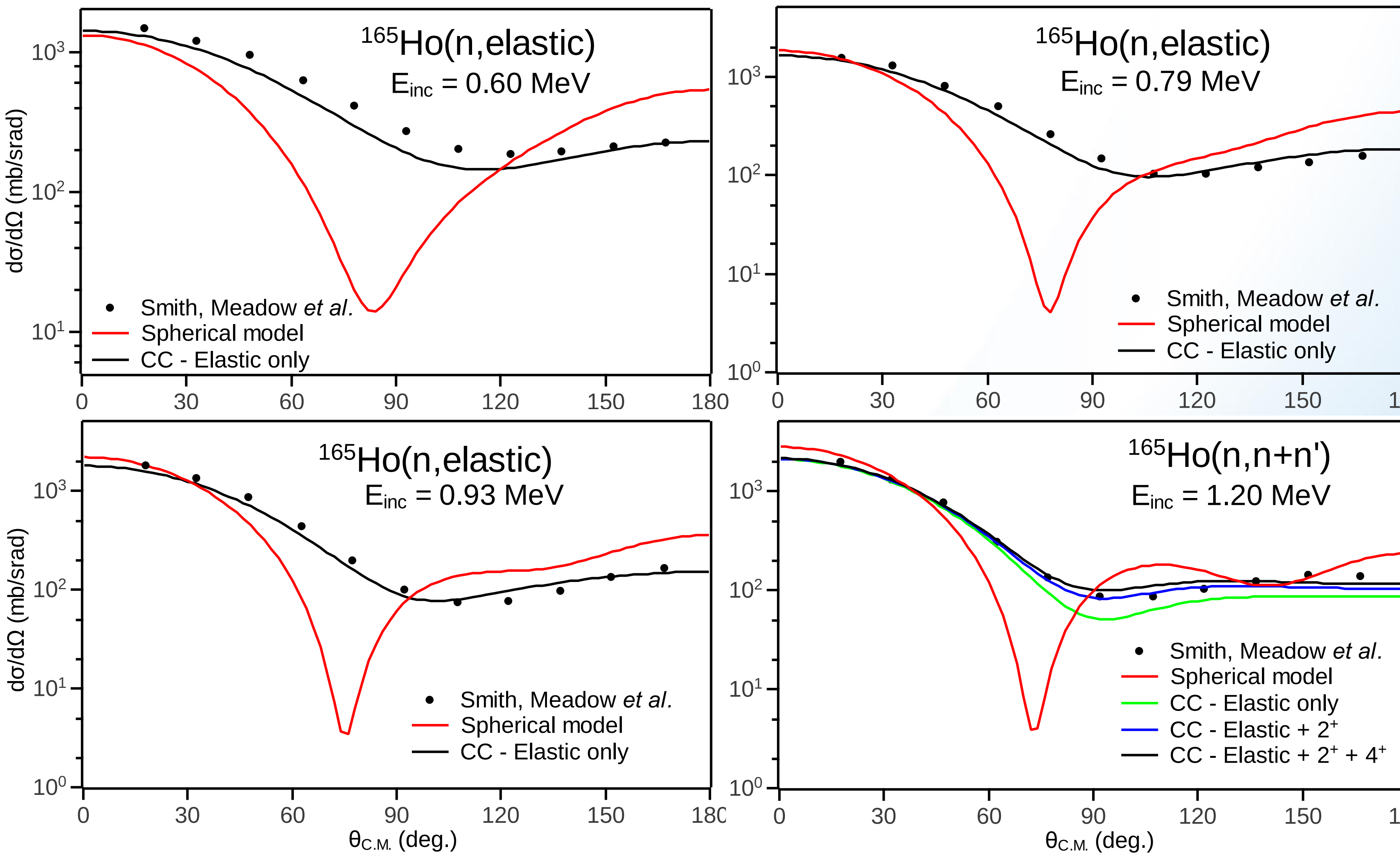
^{165}Ho experimental angular distributions contain inelastic contributions (above ~1MeV)

Below ~1 MeV: Elastic only



^{165}Ho (Quasi-)elastic angular distributions

Good agreement with experimental data obtained by the model

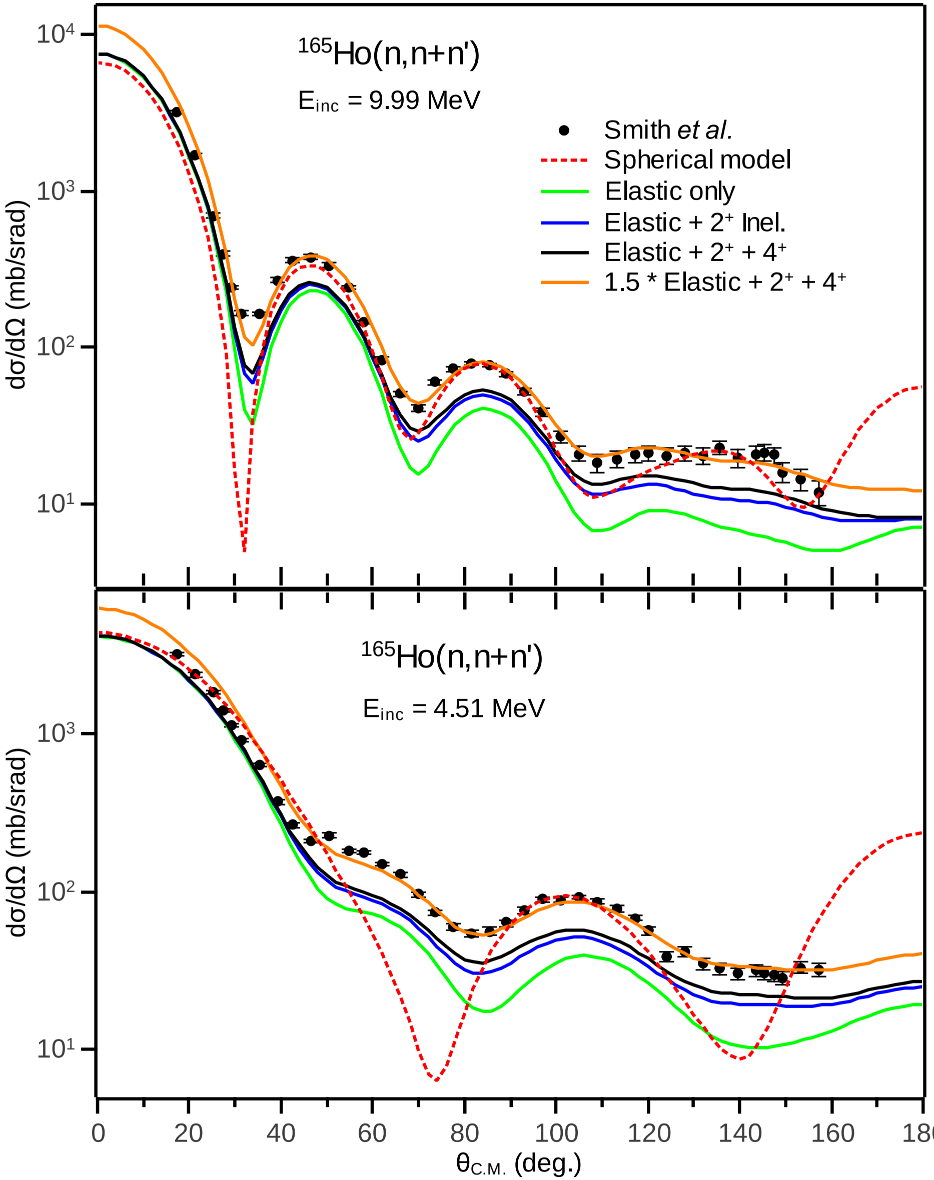


^{165}Ho "Quasi-elastic" angular distributions

In 2001, A. B. Smith published measurements of quasi-elastic angular distributions for n + ^{165}Ho, at 4.51 MeV ≤ E_{inc} ≤ 9.99 MeV

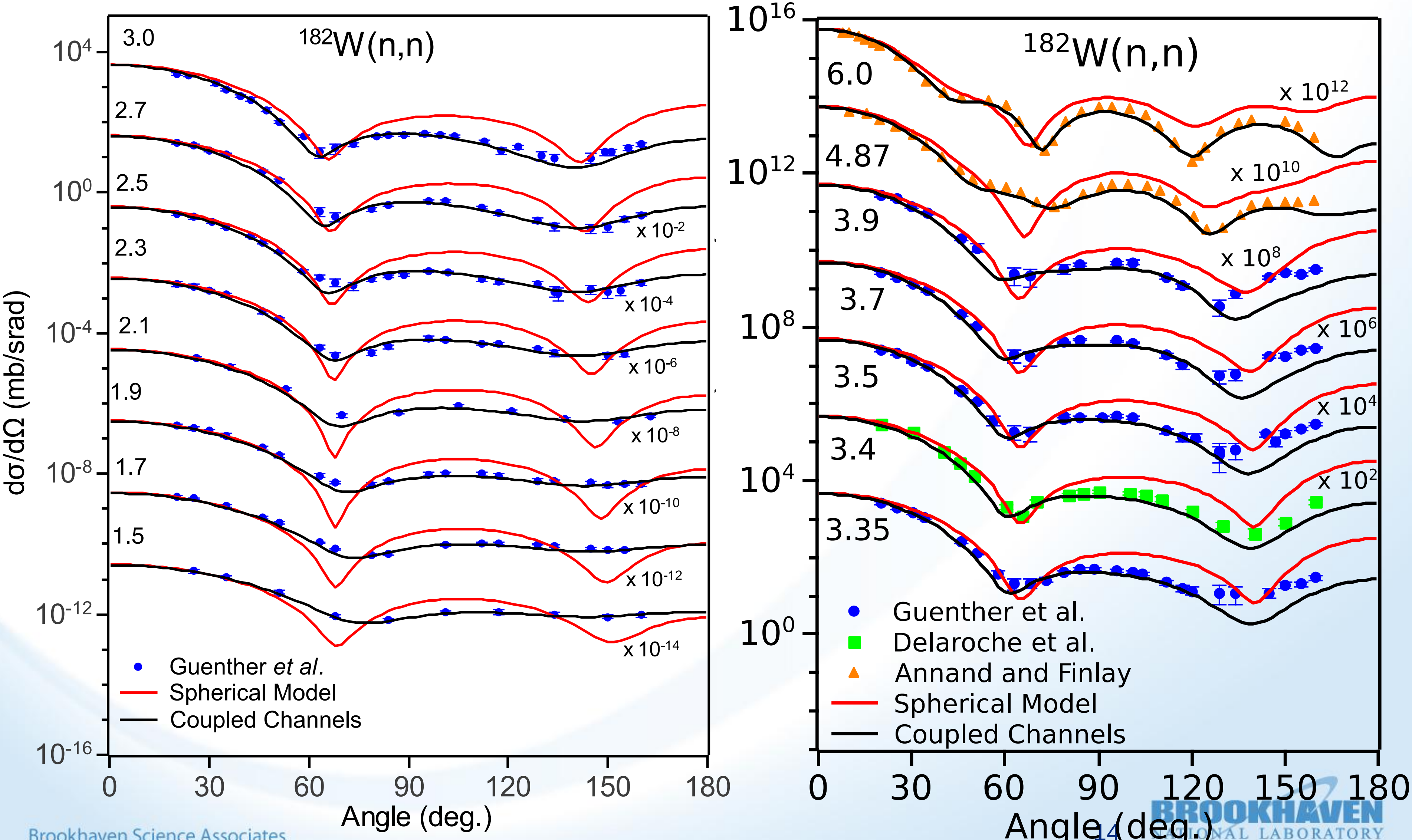
Inconsistency with other experiments

Advantage of a more fundamental (and not fitted) optical potential becomes explicit



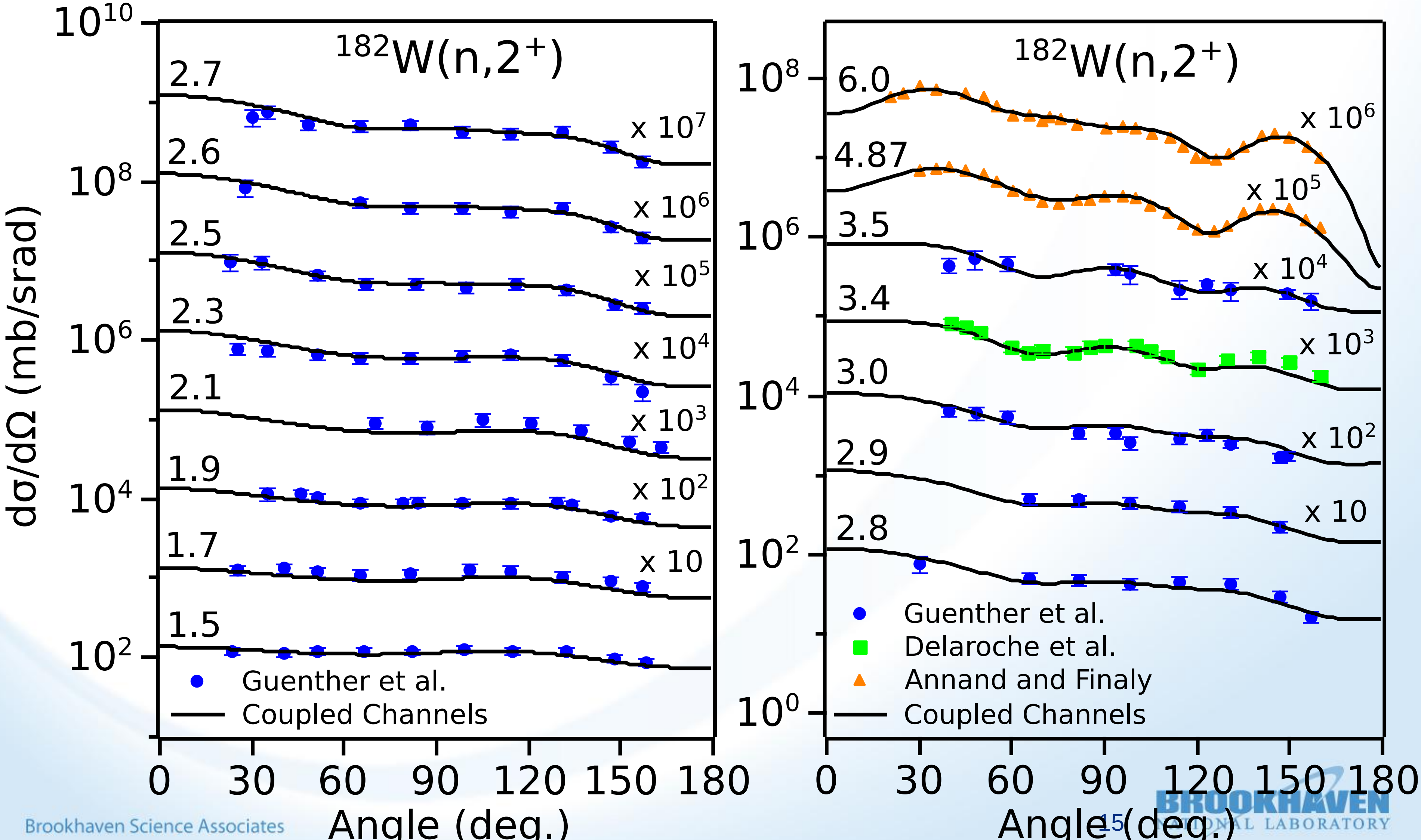
^{182}W – Elastic angular distributions

Good agreement with experimental data obtained by the model



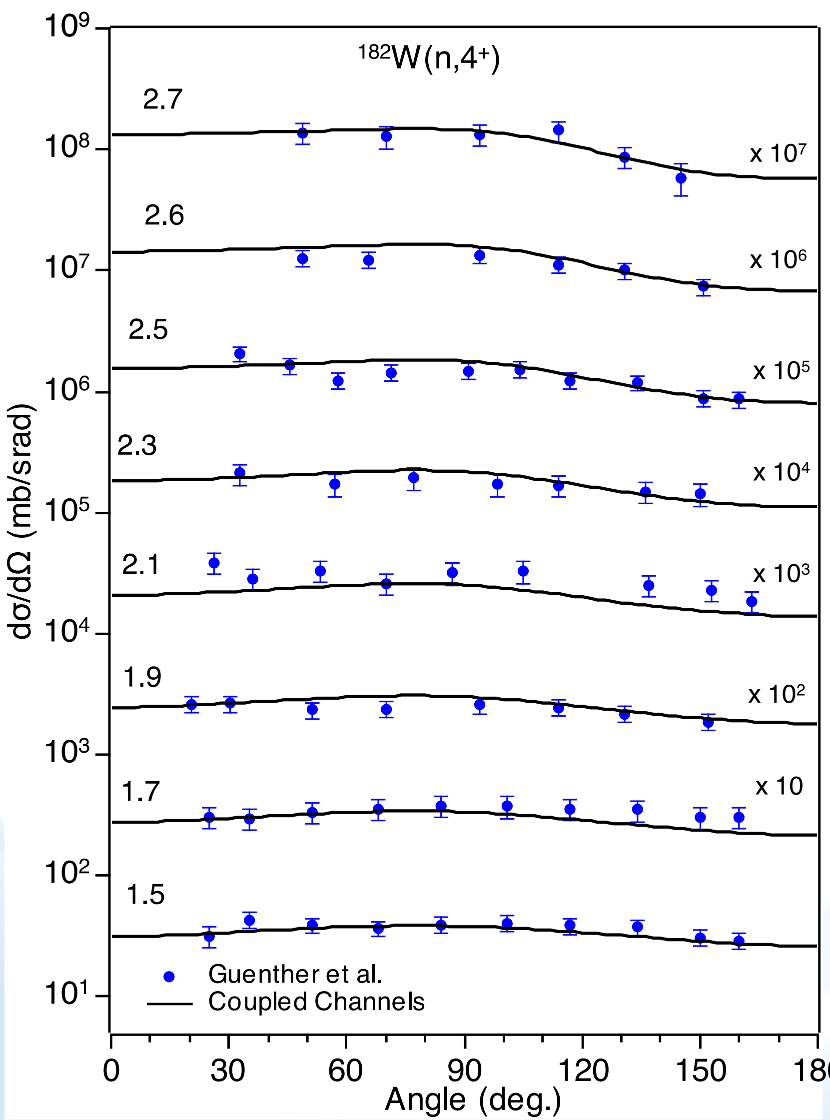
^{182}W – 2^+ Inelastic ang. dist. (E_{2^+}=0.100MeV)

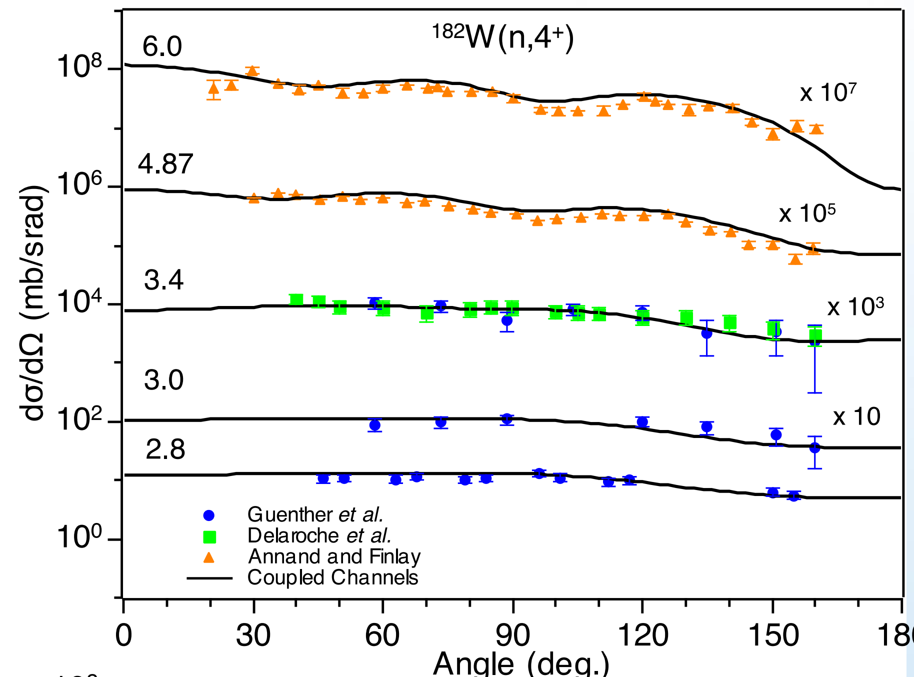
Good agreement with experimental data obtained by the model

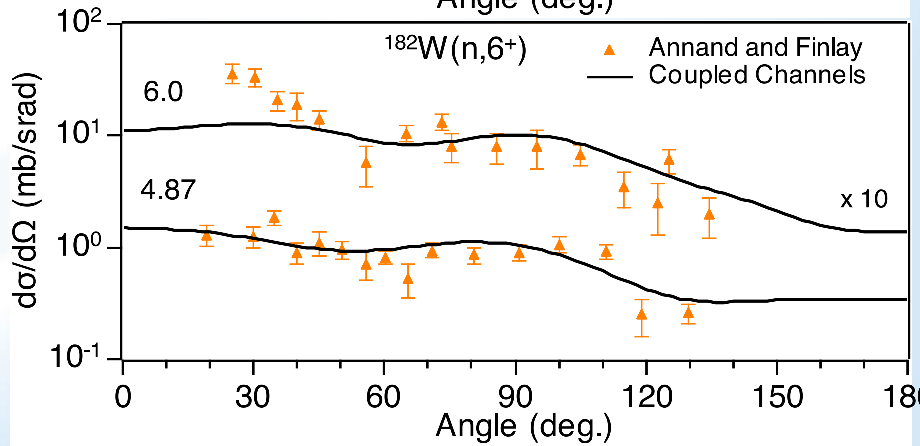


^{182}W – 4^+ Inelastic ang. dist. (E_{4^+}=0.329MeV)

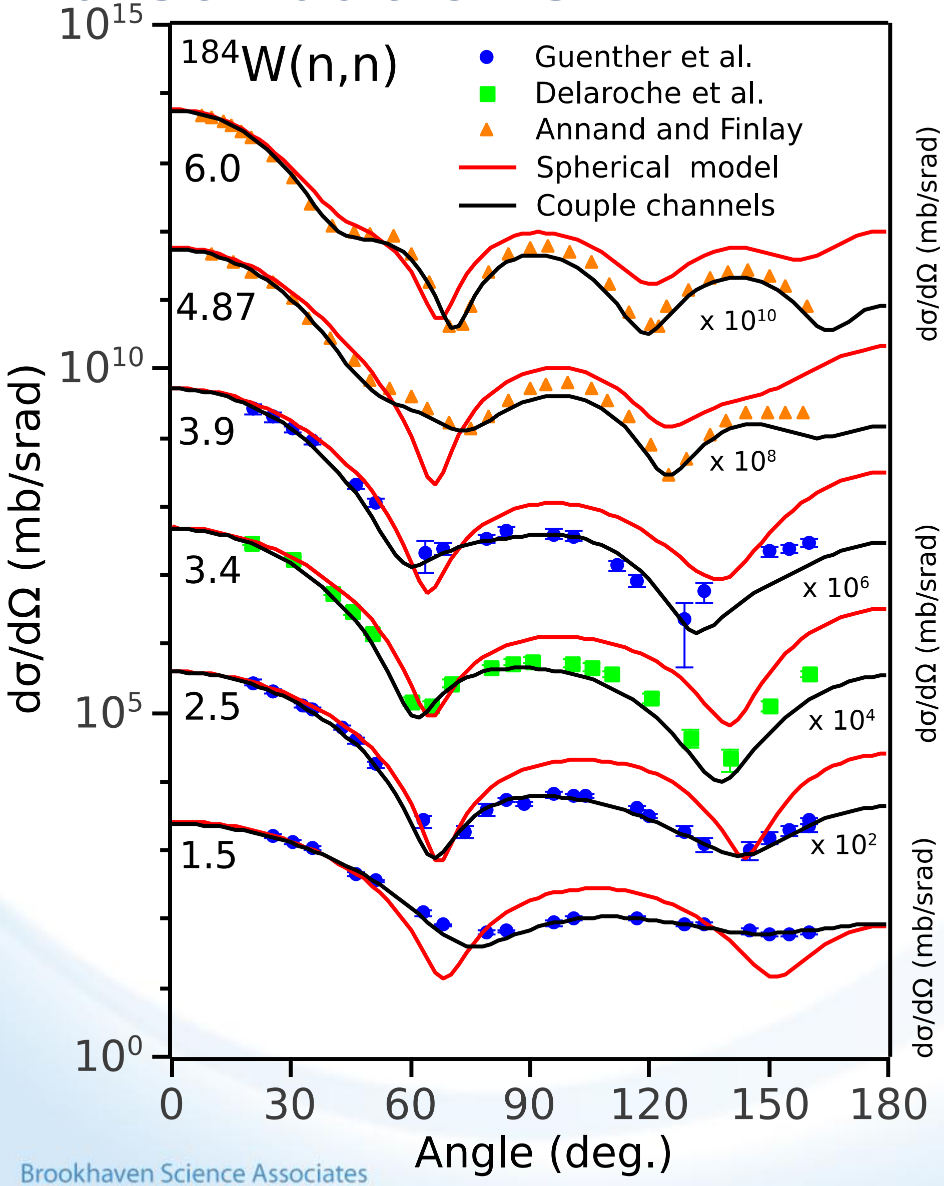
Good agreement with experimental data obtained by the model

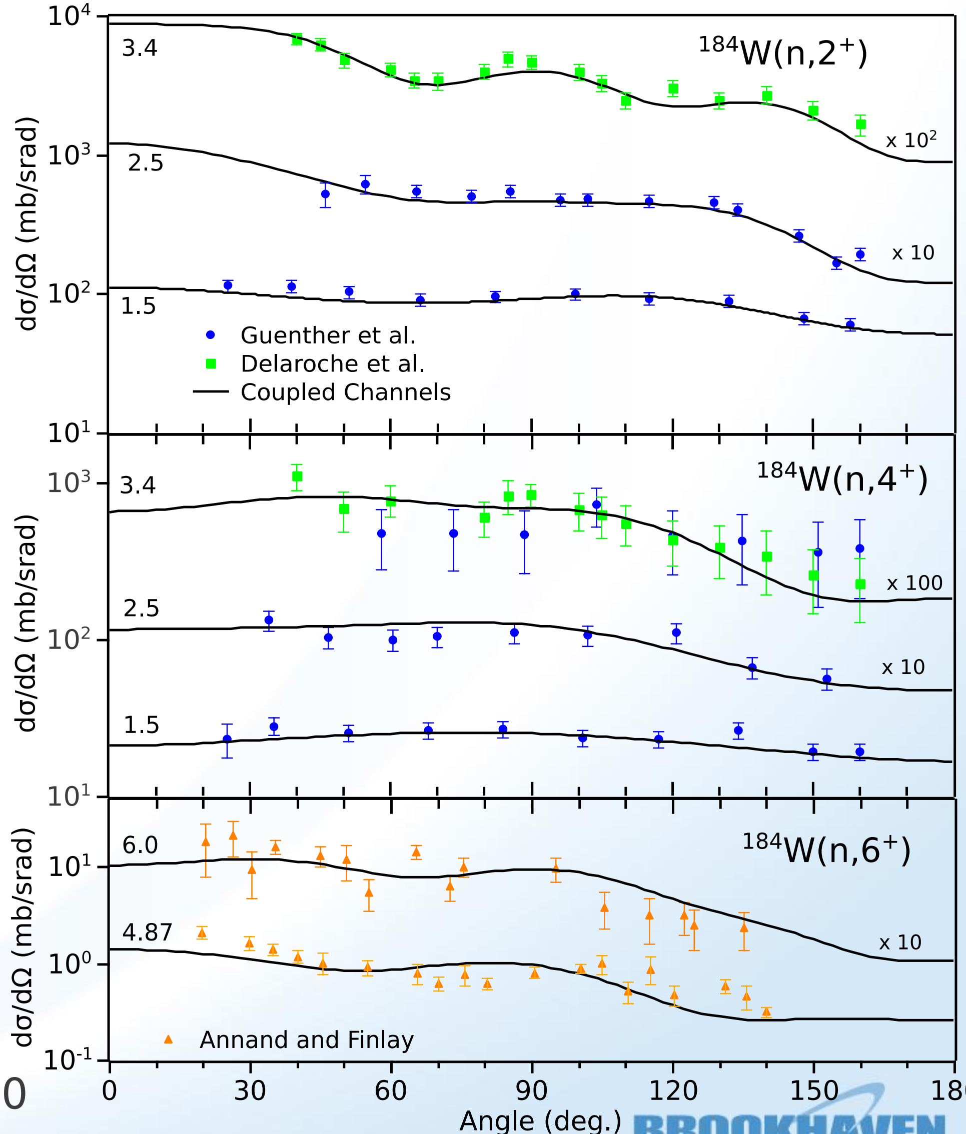




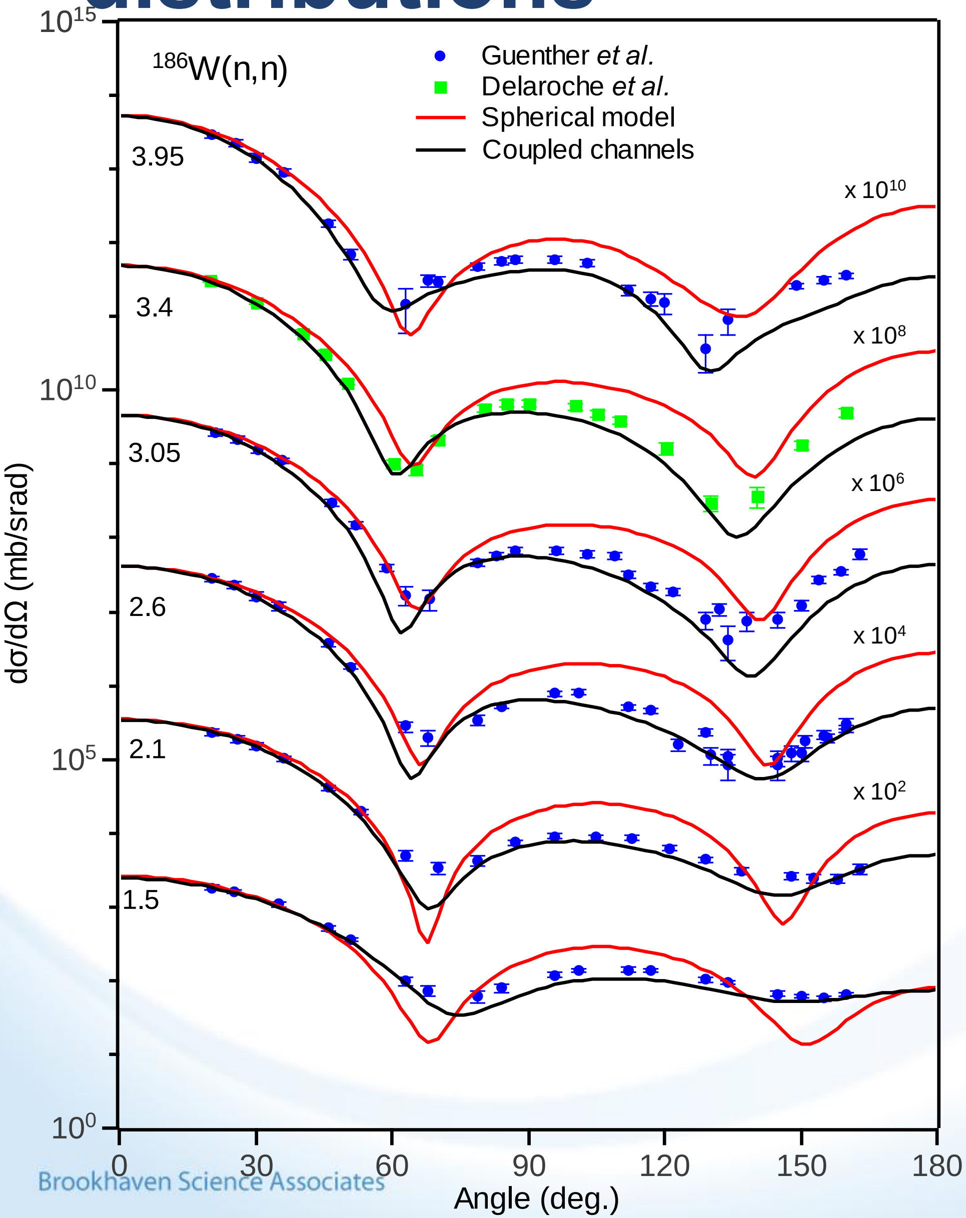


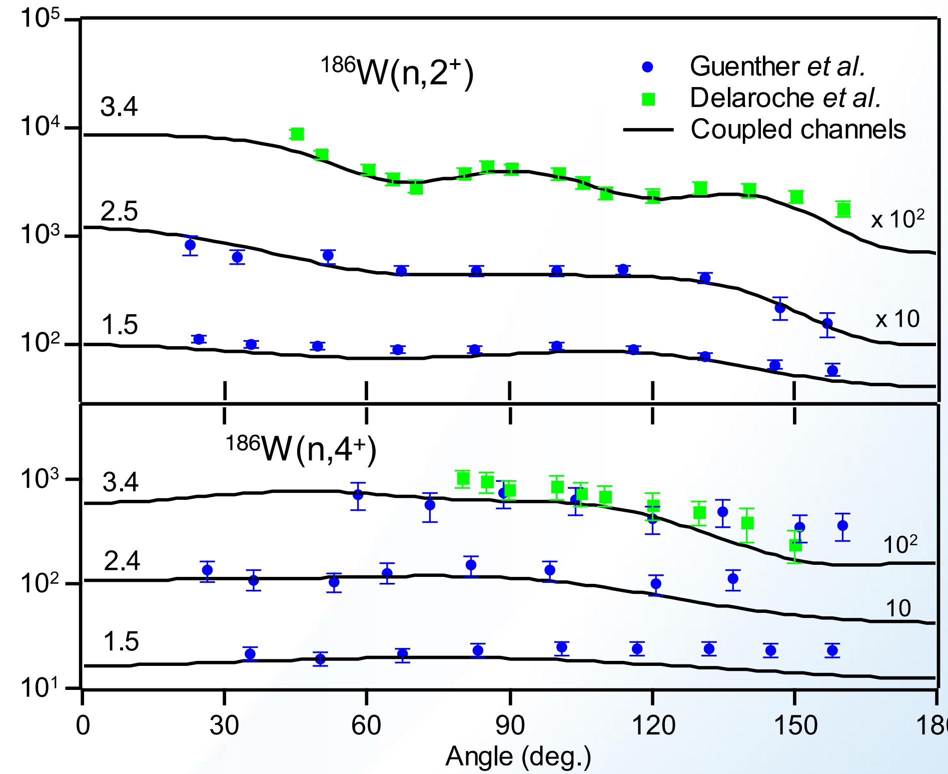
^{184}W – Elastic and inelastic angular distributions





^{186}W – Elastic and inelastic angular distributions





The fact that deforming KD allows to consistently describe observed elastic and inelastic angular distributions remarkably well is very supportive of the model and of the adiabatic approximation.

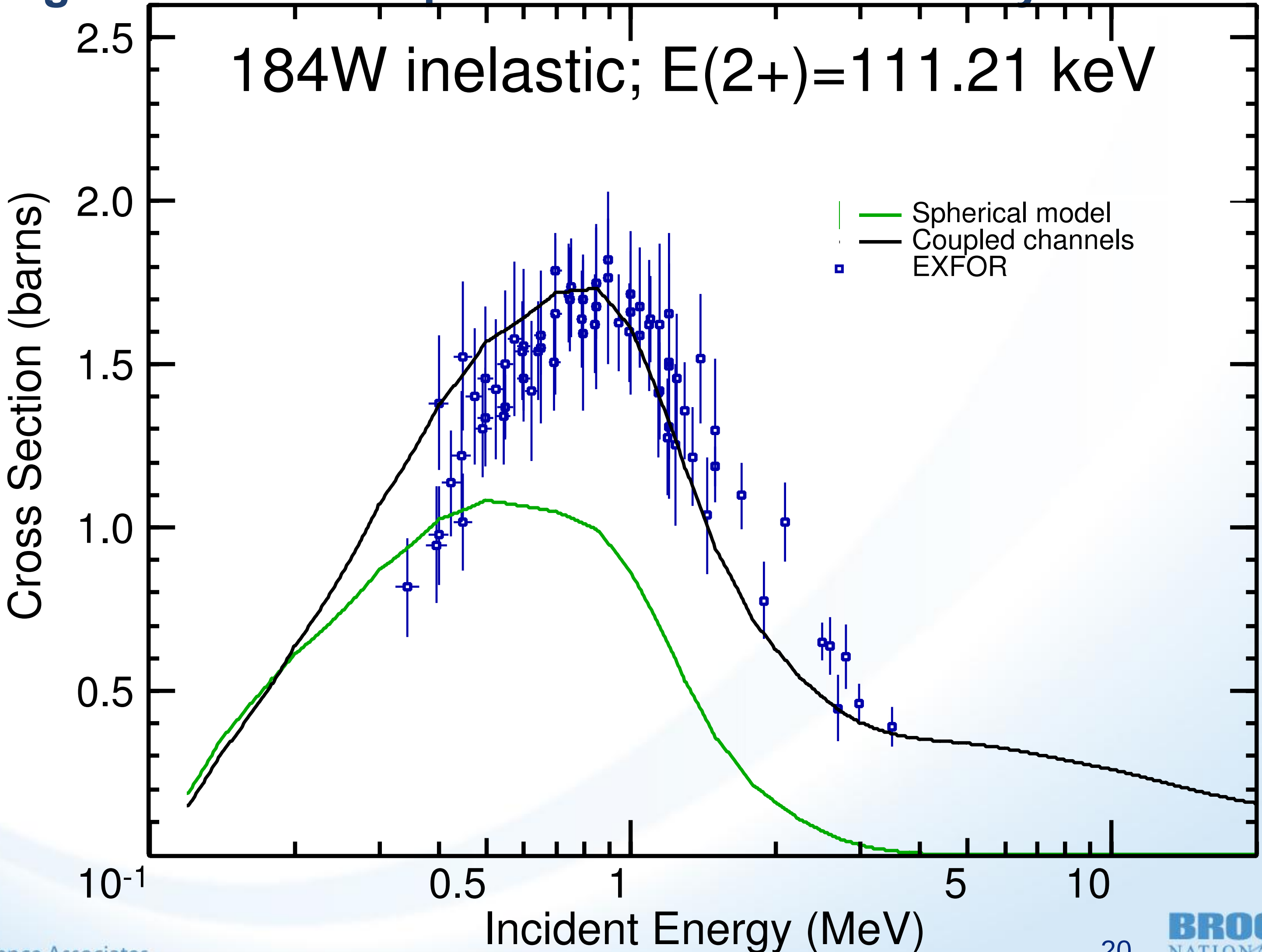
Conclusion

- We deformed spherical KD potential in CC calculations to describe statically-deformed nuclei
  - No free parameters (experimental deformations)
  - Radius correction gives (small but) noticeable effect
- This approach provides provides remarkable results for
  - Total, elastic, inelastic cross sections
  - Elastic and inelastic angular distributions
- Improvement of capture cross sections, in particular their shape

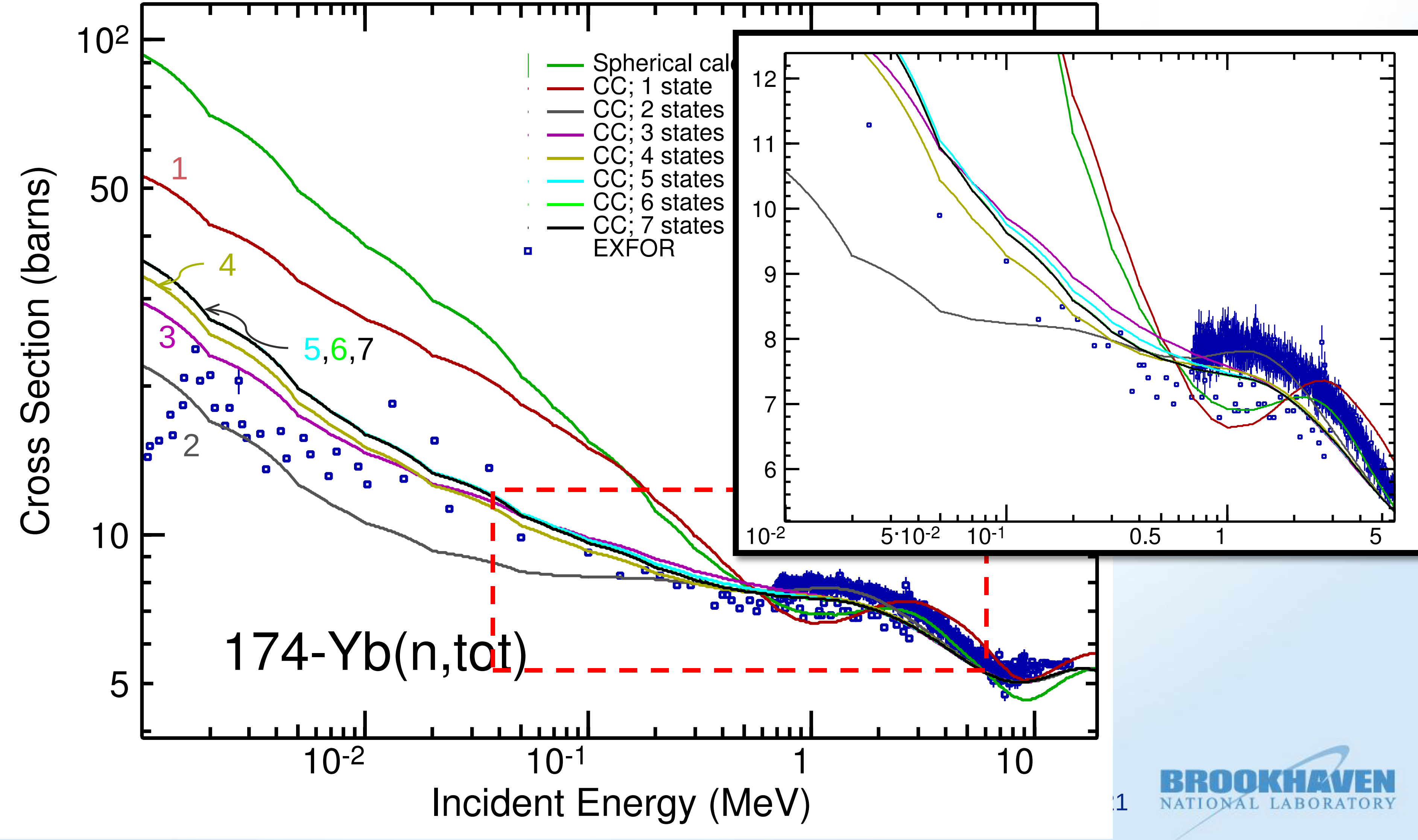
This simple method is a good, consistent and general step towards an OP capable of fully describing the rare-earth region, filling the current lack in this important region.

Angle-integrated inelastic cross sections

Good agreement with experimental data obtained by the mode



Convergence on number of channels



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Sensitivity to deformation

Deformation uncertainty relates to cross-section uncertainty